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Special Scientific Report No. 21

STUDIES ON THE PACIFIC PILCHARD OR SARDINE

(SARDINOPS CAERULEA)

3.--Determination of Age of Adults by Scales, and Effect of Environment on First Year's Growth as it Bears on Age Determination.

By

Lionel A. Walford and Kenneth Mosher

Chicago
1943

Explanatory Note

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3. - Determination of Age of Adults by Scales, and Effect of Environment on First Year's Growth as it Bears on Age Determination.

By

Lionel A. Walford, Ph. D., and Kenneth Mosher, Aquatic Biologists,
Division of Fishery Biology.

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INTRODUCTION

The objective of conservation research on the Pacific pilchard, or sardine, has been stated by Sette (1943) thus: "To determine for different levels of fishing intensity (i.e., effort), the quantity and quality (sizes of fish) in the average annual catch." The statistical computations involved in this determination require a current measurement of the age composition of samples of the commercial catch. Owing to the close overlapping in lengths of fish comprising the several ages, it is not feasible to deduce age composition or even to discover with certainty the growth rate by a study of length frequency curves. To attain these ends, it is necessary to employ some other method of determining the age of individual fishes.

The scales and otoliths of the pilchard, as in many fishes, are marked with rings which appear to be related in number to age. As usual among fishes, these marks are not diagramatically clear in the pilchard, being of various degrees of obscurity, and recognition of those that are formed only once annually (the age marks) can be easily confused by the presence of those that are formed fortuitously, the adventitious marks. In a previous report[1], the authors established criteria for distinguishing between the two types. These were critically tested on juvenile material sampled from the bait fisheries of California, and found to serve satisfactorily for determining ages up to the third year.

It is now proposed to test the application of these criteria to the scales of adult fish as taken in samples of the commercial catch, and to answer this question: With what order of accuracy can the age of a pilchard be determined by recognizing and counting the age marks on its scales? The results of this test and the answer to this question will furnish a basis for judging whether age reading from scales may confidently be used for age composition records needed in the various studies on this species.

Thanks are due to our colleagues for their critical attention and interest given during the development of this study; in particular, to O. E. Sette, who has suggested a considerable part of the methods that are new. We are grateful also to Dr. H. U. Sverdrup and Dr. W. E. Allen of the Scripps Institution of Oceanography, the former for his critical reading of that part of the manuscript touching on oceanographic matters, the latter for making available a large volume of unpublished data on diatom abundance. We are indebted, too, to Julius Phillips, of the California State Fisheries Laboratory, for his suggestions, cooperation, and criticism. The mounting of scales and a large part of the routine clerical work were done by employees from Works Progress Administration projects: 765-08-3-22, 65-2-08-286, and 265-2-08-34.

1/ Walford and Mosher, 1943.

THE MATERIAL: ITS COLLECTION, PREPARATION AND EXAMINATION

The material for this study was collected from the commercial fishery serving reduction plants and canneries, as detailed in Table 1.

Table 1. - Source, date, and number of specimens in scale collections used for this study

Locality	Period	No. specimens aged	Agency collecting
California:			
San Pedro**	1/10/40 - 1/16/40	686	U. S.[1] and Calif.[2]
San Pedro**	1/21/41 - 1/27/41	761	U. S. and Calif.
Monterey *	9/20/39 -12/21/39	3072	U. S.
Monterey **	10/21/40 -10/29/40	998	U. S. and Calif.
Monterey **	1/24/41 - 1/30/41	241	Calif.
San Francisco*	9/10/40 - 2/41	3546	U. S.
San Francisco**	8/40	181	U. S.
Eureka **	9/40	158	U. S.
Oregon:			
Astoria*	8/7/40 - 8/10/40	140	U. S.
Washington:			
Grays Harbor *	7/19/39 - 8/17/39	789	U. S.
Grays Harbor *	8/11/40	10	U. S.
British Columbia	7/22/40 - 9/21/40	832	B. C.[3]

The entire fishing seasons were sampled systematically by the Fish and Wildlife Service at Grays Harbor, Washington, in 1939 and 1940; at Monterey, California, in 1939; and at San Francisco, California, in 1940. In 1940, the Fisheries Research Board of Canada collected scales at Barkley Sound; these the board, through the courtesy of Dr. John Hart, contributed for the present study. In addition, special samples were gathered in collaboration with the California State Fisheries Laboratory at Monterey in 1940 and at San Pedro in 1940 and 1941. Other special samples were taken, as shown in table 1, for various purposes. The specimens collected at Eureka, California, were from pilchards from the stomachs of whales landed by the Whaling Station of the San Francisco Sea Products Company, and through the courtesy of the Station, sent periodically to our laboratory. In addition, scales collected in 1941 - 42 in collaboration with the California State Fisheries Laboratory, are drawn upon in this paper for illustrative or corroborative purposes.

In the regular collections a sample consisted of 50 fish, taken at random, without regard to size, from one boat's catch. As many samples were taken daily as to occupy a man's full time in collecting, measuring, and tabulating.

* Collections made in conjunction with routine sampling.
** Collections made for special purposes.
1/ United States Fish and Wildlife Service.
2/ California State Fisheries Laboratory.
3/ Fisheries Research Board of Canada.

Body length of the fish was measured as described by Sette (1941). For each sample, scales were obtained from the first 10 specimens having any still attached. Generally about 10 or 12 scales were taken from the side of the body near the region touched by the tip of the pectoral fin. As necessity required, however, fewer were taken, sometimes only one, and from wherever they could be found.

As the scales were collected from each fish they were placed in a small vial of water to which had been added about two drops of 2 percent phenol for preservative. The vials were kept in covered trays, 50 to a tray, and held in numbered places by round slots bored in the bottom. The collections were sent daily to the laboratory at Stanford University, where they were mounted.

Generally the field man assigned to the sampling work was able to take five samples daily, that is scales from 50 fish[1/]. In Washington, whenever the landings were too few to permit collection of this number of samples, scales were taken from enough specimens to bring, up to that time, the daily average to 50.

In the laboratory, the scales were cleaned and dried by rubbing between the fingers, and mounted between two dry, clean slides which were then bound together at the ends with cellulose tape. The mounted scales were examined with the aid of a projecting microscope. For each specimen a paper strip printed with a millimeter measure was laid on the image along the midlongitudinal axis of the sculptured part of the scale with the zero line at the base of the sculptured part. Locations of annuli were traced on the paper strip and later recorded as dimensions after reading the millimeter measure.

These, as well as such pertinent data as sample number, length, and sex of fish, locality and date of collection, name of reader, dimensions of scale, position of marks, calculated length of fish at past ages, etc., were recorded on a punch card, providing a permanent detailed record for every scale reading.

It required two hours for one person to mount 50 scale samples; two hours for one person to read 50, and about four hours for one person to tabulate the data, calculate growth increments, punch the cards, and check these steps for 50 readings. Thus the routine processes in the laboratory required about eight man hours for one day's field collection from one port.

The readings were all done by the authors. With certain exceptions, to be discussed below, each examined alternate samples of scales, Walford the odd-numbered ones, Mosher the even. By this method a check could be furnished on each man's reading, since the two sets, on theoretical grounds, should be satistically homogeneous if the operators used identical standards for interpreting annuli. The results of this check will be discussed below.

Occasionally the scale collection from a specimen was obviously contaminated with one or more scales from other fish. When that occurred, the material was discarded unless at least three quarters of the scales were obviously from the same fish, in which case these were read.

1/ Beginning with the 1941-42 season, an effort was made to sample approximately one-fifth of the landings.

The criteria of an age mark as set forth previously (Walford and Mosher, 1943) remains unchanged, namely:

> "An annulus is concentric with the margin of the scale. It is not always a sharp or unbroken line; nor are the segments of an interrupted annulus always perfectly co-circular (if the shape of a scale may be called circular in this discussion). But the course of an annulus, continuous or broken as it may be, can usually be traced, by careful scrutiny if necessary, entirely around the sculptured part of the scale from left-hand to right-hand margins. Sometimes they can be followed even around the unsculptured part. Annuli are clearly separated from each other and do not ordinarily meet at any point. If an annulus has formed, it is present in all the normal scales of an individual."

In the scales of fish older than six years, the peripheral annuli are crowded and frequently irregular, so that they cannot be made out equally well entirely around their course, particularly in very old specimens. On such scales, the annuli are generally most distinct at the anterior "corners" of the sculptured part of the scale (see figure 1). There they are most easily located and counted, and thence they can be traced, even though with difficulty, entirely around the sculptured part of the scale. The criteria of a false year ring, given previously (Walford and Mosher, 1943) apply for older fish as well as for younger ones. These are:

> "They are merely short or unassociated arcs; or if they completely circle the sculptured part, they are usually not concentric with the margin; furthermore, they frequently join an annulus at the base. In any case, they may be less distinct than an annulus, being vague and indefinite, or they may be much more distinct, having a scar-like appearance; that is, with very pronounced irregularities of pattern, the folds being broken or otherwise obviously abnormal. They rarely appear in all the scales of an individual."

ERROR OF INTERPRETING THE ANNULUS

Having established certain definitions of an annulus and of an adventitious mark, it is pertinent to learn how accurately they can be employed. Expected errors are of two types: those caused by faults of the scale and those caused by faults of the reader.

Of the first type are those cases in which a scale fails to record a year mark; also those in which an adventitious mark may look enough like an annulus easily to be mistaken for one. These cases of scale faults provide exceptions to our criteria of true and false annuli, and they are as liable to the same interpretation in a second examination as are normal scales. The percentage of errors arising from these causes probably can never be directly measured.

Of the second type are those cases in which a reader simply mis-counts the rings on a clearly marked scale; or those in which he overlooks one or more unusually obscure marks; or those in which, by faulty judgment, he miscalls an adventitious mark a true annulus. These errors are, in general, the fault of the reader, and are relatively unsusceptible to duplication in a second reading, particularly by a different reader. Therefore, the results of parallel readings may be expected to provide a measure of the personal error--the reader fault--in interpreting our criteria of year marks and in counting them.

Scales of 1,187 specimens from the San Francisco fall fishery of 1940 were read by Walford and by Mosher, each working separately and independently. Subsequent comparison showed that 1,049 or 88 percent of the pairs of readings were identical. The 138 specimens for which readings were in disagreement were then subjected to a third examination, this time by the two operators working jointly, and without reference to either of the two previous readings. On this occasion, 4 specimens were discarded as unreadable[1/]; 123 of the joint readings agreed with one or the other of the two previous readings ("single disagreements"); and 15 were different from either ("double disagreements"). In 31 instances the "single disagreements" concerned the innermost ring, in 49, the marginal ring, and in 43, one of the intermediate rings. In terms of percentage these quantities are 25, 40, and 35, respectively. Since the average number of rings present in specimens of this group is 4.2, these percentages should be close to 25, 25 and 50 respectively, if all rings were equally difficult to recognize. Obviously, the marginal ring was more obscure than the others. Indeed, during the joint readings, it was found that uncertainty about the criteria for recognizing a newly formed ring at the margin during January and February was the cause of several of the disagreements, and a special study was indicated (see page 9).

A similar test was made by three workers, Walford and Mosher; and Phillips of the California State Fisheries Laboratory. Scales from 483 specimens, read first by Phillips, were subsequently divided into two lots, of which one was read by Walford, the other by Mosher. The two sets of readings, i.e., by Phillips and by Walford-Mosher, were identical for 431 or 89 percent of the scales. The 52 specimens for which readings were in disagreement were then subjected to a third reading, this time by the three workers together. When these joint readings were compared with the original readings, it was found that three disagreed with both Phillips and with Walford-Mosher ("double disagreements"), and 49 agreed with one or the other ("single disagreements"). Disagreements concerned the first annulus in 13 of the cases, the marginal annulus in 15, and an intermediate one in 21: or, expressed as percentages: 26, 31, and 43, respectively. Thus there was no marked tendency for any one annulus to cause more disagreement than any other.

A third test with parallel independent readings was made by Walford and Mosher on 973 specimens taken from Washington. This sample contained a higher percentage of fish over three years old than those described above. For that reason, and also because the scales had not been well cleaned when collected, this test was more severe than the others. Nevertheless the two readers agreed in 709 or 73 percent of the cases. Of the remainder, 235 were "single disagreements", and 29 were "double disagreements."

1/ Less than 0.2 of 1 percent of the scales had been discarded as unreadable on first reading. These were specimens with regenerated centers.

Thus in three tests involving parallel readings of 2,643 specimens, there was disagreement on 454 of the cases--"disagreements"--and agreement in 2,453--"agreements." When the former were re-examined by the two participating workers, the final decision agreed with one or the other of the two original readings in 408 cases and disagreed with both in only 46.

In close to 90 percent of the cases, disagreement involved a choice of two adjacent ages, and, therefore, uncertainty as to the existence of only one of the rings; and only 10 percent involved uncertainty as to more than one ring. Save for the first of the three tests, no one annulus was the subject of disagreement more frequently than any of the others. For the first test, disagreement over the marginal annulus, which was somewhat in excess of expectation, was later corrected as a result of a special study (see page 9).

A reader's decision as to which of two adjacent ages a "disagreement" should be referred, might possibly be determined by chance. Assuming this to be true, half the specimens should be assigned to the younger age, half to the older. Consequently the size composition of fish comprising the two halves should be statistically identical, and should agree equally well or badly with the size composition of the "agreements" of the two adjacent ages in question. To examine this hypothesis, a series of chi-square comparisons was made, the results of which are summarized in table 2. The tabulated figures give the probability of obtaining, in a second series of samples, differences in size composition as great or greater, by random error.

Table 2.- P values obtained on chi-square comparison between size composition of agreements and revised disagreements.

Agreements, number of rings	Final determination on revised disagreements: Number of rings						
	3	4	5	6	7	8	9-
3	.74(2)[1/]	.001(2)					
4	.004(2)	.26(3)	.001(5)				
5		.001(4)	.16(7)	.001(5)			
6			.0015(6)	.08(5)	.001(4)		
7				.001(4)	.90(5)	.001(4)	
8					.001(3)	.72(2)	.00(1)
9						.01(2)	.60(1)

[1/] Figures in parenthesis indicate degrees of freedom.

According to table 2, the size distribution of the fish yielding "agreements" on a given age, when compared with that of fish assigned to that same age by revision of readings that had originally disagreed ("revised disagreements"), gave $\bar{P}$ values high enough to indicate that the two distributions had been of the same population in the statistical sense. On the other hand, when a parallel comparison was made with adjacent year classes, the $\bar{P}$ values were all so low that there could be no question that the fish were of different populations in the statistical sense. It appears, then, that the final decisions on the disagreements were not determined by chance, but must have been, on the whole, corrections of errors in the first reading.

It is, of course, not possible to know the absolute error of the final determinations. Among the "agreements" can be erroneous readings that agree by chance; but for scales of ordinary difficulty the number of these is probably low, being something less than one percent of the cases[1/]. In addition, there must be errors among the joint readings.

There may be more of these than are found among "agreements," since only the more difficult scales tend to be the subject of disagreement. Furthermore, the final decisions in the joint readings may be determined often by the domination of one of the participants. Finally, there are the errors resulting from scale faults, referred to above.

Errors from all these causes are not measurable by any known methods. The material and methods at hand provide merely this incomplete measure: If B disagrees with A, A is not held to be in error if a joint reading concurs with him rather than with B. Hence, an index of a reader's error is the number of age determinations with which there is disagreement in both a parallel reading and in a subsequent joint reading, expressed as percentage of the number of specimens aged. For the three tests discussed above, this index of error, by ages and by three readers, A, B, and C, totalled as given in table 3.

Table 3. - Index of error

Number of rings	Number of specimens read by reader			Number of errors by reader			Index of error by reader		
	A	B	C	A	B	C	A	B	C
1	66	66	26	1	2	6	1.5	3.0	23.0
2	272	225	318	5	5	13	1.8	2.2	4.1
3	862	853	112	22	39	8	2.6	4.6	7.1
4	684	683	20	49	62	4	7.2	9.1	20.0
5	253	235	7	28	29	1	11.1	12.3	14.3
6	164	181	0	12	33	-	7.3	18.2	-
7	62	66	0	14	20	-	22.6	30.3	-
8	31	40	0	4	7	-	12.9	17.5	-
9	33	27	0	9	10	-	27.2	37.0	-
	2,427	2,376	483	144	207	32	5.9	8.7	6.6

1/ This is based on the average known error of each man being close to seven percent. The probability of both misreading any one scale on the average, assuming purely random error, is $(0.07)^2 = .0049$.

Table 3 gives evidence that the index of error varies from age to age, being higher for the older than for the younger classes; and, therefore, the error on age composition must vary according to the number of old fish present. The index of error varies from reader to reader; also for any given reader, from time to time, being more or less proportional to the degree of his fatigue. It has been our experience that readers sometimes unconsciously adopt faulty reading techniques which result in their making some types of errors consistently over a period of time. Thus, Reader C (table 3) tended during the test to overlook the marginal ring on scales with two annuli, and consequently he recorded an excess of yearlings. Faults of this kind are detected and eliminated during the joint readings.

To avoid such errors, frequent tests should be made. Indeed, it would be desirable to make parallel readings of all scales were it not impractical in routine work involving several hundred specimens weekly. Fortunately, at least 95 percent of the California catch is composed of fish younger than 5 years, for which the index of error is low enough to justify substituting for parallel readings the procedure described below. For the remainder, the relatively high error necessitates making parallel readings on all specimens.

In the light of the foregoing results, the following procedure was adopted for future routine work: The slides will be dealt among the several readers like playing cards, so that all have equal-sized, randomly distributed portions that should prove to be statistically identical as to body length composition. That being true, the age compositions of the several portions should also be statistically identical; and significant differences among them should be detectable by the chi-square test, as described below. Wherever such differences occur, the scales will be re-read and the cause of the differences found and corrected. Meanwhile, specimens aged as five years or older will be given parallel readings; and joint readings will then be made of the disagreements.

Following this procedure, the scale collections taken during the 1940-41 season at San Francisco, 3,210 in number, were dealt between Walford and Mosher. That the two portions were statistically similar in size composition is indicated by a chi-square comparison, which gave a probability of 0.58 that a second pair of samples drawn from the same population would differ in size composition as much or more by chance alone.

For the same reason, if these two random portions were alike in size composition, they should be alike in age composition. A chi-square comparison was therefore made between the totals of each year class in Walford's portion and those in Mosher's. This test gave a probability of 0.13 that a second pair of samples drawn from the same population would differ in age composition as much or more by chance (chi-square was 8.4 with 5 degrees of freedom). Though high enough to be acceptable as evidence that Walford and Mosher had, in the main, read their respective lots of scales alike, it is at the same time low enough to suggest the presence of some non-random differences between the two series of age distributions, due, possibly to some difference in the interpretations of the two readers.

To learn then whether such a difference might be centered about fish of certain size categories, a chi-square comparison of age composition was made for each size class.

For this purpose, size classes were made as small as possible--usually two millimeters--but large enough to contain, for each member, a minimum of ten specimens. The results of this analysis indicated no significant differences between the two readers--all P values were well above .05-- except for eight classes in the size range 211-226 millimeters. For each of these was indicated a probability of less than 0.001 that a second pair of samples from the same population could differ as much or more by chance. Accordingly, scales of the 1,131 fish in this size range were reexamined, the two readers exchanging their respective portions so as to check each other's first interpretations. It transpired from the subsequent joint readings of the disagreements, that the chief cause of disagreement had been confusion as to the criteria for distinguishing between old and new rings at the margin, particularly during January and February, when accelerated growth is exposing the newly formed annulus.

This difficulty was at length resolved by a special study as described on pages 9 to 11, which provided an objective method of making the necessary distinction. After the method had been applied, the two original portions, Walford's and Mosher's, were again compared as to age composition, by the chi-square test. On this occasion the probability was 0.44 that the two distributions would differ as much or more by chance in a second pair of samples drawn from the same population.

Thus an equivalent of parallel reading has been devised, which saves considerable labor, yet serves to detect and correct errors in the interpretation of the criteria of age marks. The method was applied during the 1941-42 season, when three persons were employed. The average P value obtained on first readings was .48, indicating no significant difference in results among the three readers[1/].

RECOGNITION OF THE NEW ANNULUS

In a previous paper (Walford and Mosher, 1943), it was shown that the new annulus appears on the scales of young pilchards, up to three years of age, from late fall to early spring. Judging from the present data, it appears at the same season in the scales of adults. Because commercial fishing

1/ It has been suggested by those critically reading the manuscript of this paper that the above discussion tends to over-simplify age determination of pilchard scales. It must be emphasized that a considerable degree of judgment must be exercised in recognizing age marks. This requires skill obtained from experience illuminated by knowledge of the biology of growth. It also requires much patience and a certain sympathetic attitude toward scale reading. Nevertheless, the evidence described on pages 11ff was obtained despite the subjective nature of these imponderables. It appears, however, that age reading cannot be practiced equally successfully by all investigators.

for adults is carried on only from late July or August to February or March, and fish in sufficient quantity for study are not available during the intervening time, it is not feasible to follow an entire year's cycle for adults as it was for the young. In July, however, when specimens were first taken, the last ring was found to be fully formed in all examined, and was completely surrounded by a narrow marginal growth zone; and no specimens were found with developing new rings. During succeeding months the margin beyond the last ring seemed to increase in width, and by late fall new rings began to appear in a few specimens. While these were in the process of formation, they could be easily distinguished from old rings by the following criteria:

an annulus is recognized as forming when it does not appear entirely around the sculptured part at once, but generally only on the most distal parts of the edge (see figure 3); or, when it extends entirely around the sculptured part, it touches the edge at one or more points.

These criteria seemed to serve for distinguishing new rings until about early January. From then on, however, an increasing number of specimens occurred with the last (submarginal) ring remarkably close to the edge of the scale, but complete, and entirely bounded by a marginal zone. For these the above criteria could not be applied. Instead, at the time of first reading, the operators tried to judge whether they were new by whether or not they were at any point of their course obviously closer to the edge than could be accounted for by a year's growth. Unfortunately, there are intermediate cases which could be attributed equally well to a year of abnormally slow growth or to a few weeks of abnormally rapid growth. Consequently, the decisions on these cases rested more or less with chance, and as shown by the studies on parallel readings, this was one of the chief causes of disagreement among the readers.

In an effort to devise an objective standard for distinguishing new from old rings, therefore, a statistical study was made on the width of the marginal growth zone. One would expect the latter to be narrowest shortly after a new ring has formed; and to increase thereafter in width during the year, reaching its maximum just before the following new ring appears (Walford and Mosher, 1943). Accordingly, the distance between the last annulus and the edge of the scale--the marginal zone--was measured to the nearest 0.2 millimeter of projected image (equivalent to 0.00667 millimeters in actual width), on all scales taken from July 1940 through February 1941.

These data were tabulated by number of rings (not by assigned year classes), according to width of margins, in the form of a frequency distribution. For example, all scales having four rings were tabulated together. It would be expected that early in the season, they would all be of year class 1936; later in the season some of them (those with new rings) would be of year class 1937. The two groups would be expected to have the same relative variation about their respective means, and to put this on an absolute basis for purposes of graphical study, sizes were converted into logarithms, which were tabulated into classes of equal intervals (Schrek and Lipson, 1941). In figure 5 the results of this transformation are given for scales with four rings, as an example of a case of average difficulty. A dominant mode to the right, which can be followed through the season, is taken to represent the margins attributable to the past season's growth; and a new mode to the left, appearing in November, probably represents margins attributable to the next season's growth.

These data have been fitted with normal probability curves, according to a graphical method devised by O. E. Sette (unpublished manuscript). A single normal curve fits the data for July-August and for September-October. This group is assigned to year class 1936. It obviously persists through the season, retaining certain consistencies, namely, first, a mode which advances slightly, indicating slow autumnal scale growth; second a standard deviation which remains constant. For November-December, and for January-February, it was necessary to add a second, overlapping, curve on the left. This group is assigned to year class 1937. As in the right-hand group, this too has the characteristics of a mode which advances, as is to be expected, from scale growth, and a constant standard deviation.

To measure the degree to which the selection and placing of these hypothetical curves fit the empirical data, comparison was made by the chi-square method. A P value of .06[1/] was obtained, (chi-square = 30.4; degrees of freedom, 19), of borderline significance.

Chief contribution to the chi-square comes from the sixth to ninth classes. It appears, then, that the low P value first obtained was due to minor irregularities of the data, rather than to selection and placing of the hypothetical curves. If these be combined, the seventh class with the sixth, the ninth with the eighth, P becomes .56 chi-square 15.59; degrees of freedom 17).

This, then, is an objective means of allocating proportions of new to old rings where the marginal increments overlap. In the four-ring series (Fig. 1) allocations were made as follows for November-December: To the older age, 1/6 the specimens in size-class 7, 3/4 in size-class 8, 34/35 in size class 9. The remainder in these classes were assigned to the younger age. In January-February, to the older age were allocated 9/26 of the specimens in size-class 8, 31/38 in size-class 9. The remainder in these classes were assigned to the younger age.

The assignment of ages to individuals in these critical cases by the method just described, precludes using those individuals for other studies involving sizes, ages or growth, and the statistical cards were marked accordingly.

This method of solving the problem of distinguishing between new and old rings has been incorporated into the routine of age analysis in pilchard research.

EVIDENCE BEARING ON THE VALIDITY OF SCALES FOR DETERMINING THE AGE OF ADULT PILCHARDS

The foregoing section has dealt exclusively with the question of how correctly one or more scale readers can assign a given age to a given fish, or to the measurement of the "reader error". In the following discussion the effect of this error plus that of the scale error (cf. page 4) will be examined.

1/ I.e., the probability is .06 that a second series of empirical data would differ as much or more from this theoretical series of curves, by chance.

The annual occurrence of age marks in pilchards of juvenile age had been proved in the following way[1]: A stratified random sample of scales was prepared to represent equally all the months of the year. The labels on the slides were then masked, the slides mixed, and the scales examined and measured without knowledge of the size of the fish or the time of year collected. When the measurements thus obtained were collated, it was found that the marginal increment was narrower at one season--the spring--than at any other, and increased in width during the remainder of the year. Its growth was rapid in spring and early summer following the formation of the annulus in the winter, and slight from late summer to winter.

The foregoing demonstration was possible because young pilchards are available near shore in California throughout the year and are taken by the bait fisheries. "Adult" pilchards, on the other hand, are migratory, departing for their spawning place at the time of maturity, in the spring, and not reappearing until mid-summer. Hence, the commercial fishery for adults is seasonal, and the scale material collected for this study does not include an important period of the year's growth. Despite this hiatus in data, the results discussed on pages 9ff and given graphically in figure 5, indicate, as far as they go, that in adults, as in the young, the annulus appears during one season of the year--the winter, and that the marginal increment increases in width until the next annulus is formed.

For critical proof of the validity of scale reading, the annual growth increments on the scales were studied in search of peculiarities in dimensions, marks or other irregularities associated consistently with certain year classes such as Lea had discovered for the Norwegian herring (Lea 1919). To provide homogeneous data, an effort was made to select scales consistently from the same part of the body, namely the side, near the tip of the pectoral fin. Unfortunately such selection was unfeasible whenever the fish sampled were in poor condition. Under these circumstances, scales were taken wherever they could be found, often from the back or near the caudal peduncle, where pilchard scales are characteristically smaller than elsewhere. For adjustment to a common basis to permit comparative studies, therefore, scale measurements were translated into terms of body length of the fish, by means of Lea's formulae:

$$\frac{s_n}{S} = \frac{f_n}{F}, \text{ and} \qquad (1)$$

$$f_n - f_{n-1} = t_n \qquad (2)$$

Where s_n is the distance from the center of the scale to a particular annulus, n; S the distance from the center of the scale to the edge of the scale; f_n the length of the fish at the time the annulus n was formed; F the length of the fish at the time of the observation; t_n the growth increment in the year preceding the time the annulus n was formed. Hence, $t_1 = f_1$; $t_2 = f_2 - f_1$; etc. The symbol "f" is the same as Lea's "l"; it abbreviates the term "fish length" as "s" does "scale length".

[1] Walford and Mosher, 1943.

This formulation assumes simple, perfect correlation between body length and scale length, with a regression having its origin at zero. It was found, however, that the assumption is no more valid for pilchards than for many other fishes studied. The scales are not formed until the fish has reached a length of 3 to 4 centimeters. For a time thereafter, until the body becomes fully scaled, the growth rate of the scales is rapid in relation to that of the body; then it decelerates, until at length the slope of the regression, b, becomes constant. This occurs below the minimum length of fish found in our samples. Hence, for the material used in this study, the relation of scale length to body length may be expressed by a simple straight line regression of the type $y = a + bx$, and Lea's formula (1) must be modified to:

$$\frac{s_n}{S} = \frac{f_n}{F + a} \qquad (3)$$

For calculating a, the regression of scale length on body length was plotted separately for each of four year classes, those of 1936 to 1939, to which specimens had been allocated by scale studies.

The values of a and b were as follows:

Year Class	a	b
1936	-2.2378	.7326
1937	0.8464	.7285
1938	-20.3317	.8405
1939	2.0814	.7240

Significance of differences, in terms of P[1/] (according to Fisher's t test) is as follows:

Year Class	Compared with Year Class		
	1939	1938	1937
1936			
a	.30-.40	.01	.40-.50
b	.50	.01	.50
1937			
a	.50	.01	
b	.50	.01	
1938			
a	.01		
b	.05-.10		

In regression of scale length on body length, year classes 1936, 1937, and 1939 did not vary from each other beyond the range of random error; but year class 1938 differed significantly from each of the other three, both as to a and b.

1/ That is, the probability that if an additional pair of samples be drawn from the same population, they would differ as much by chance as the two under comparison, or more.

Thus the fish assigned to one year class had an intrinsic quality in common in addition to the number of rings on their scales, peculiar to their class, which persisted during three years of this study. It is fortunate that this peculiarity applies to year class 1938, for it is that class on which the most complete collection of material is at hand, going back to first appearance in the bait fisheries, when identification of its age as fish of the year was virtually beyond question. And it is that class from which the material was drawn on which the validity of age determination of juvenile pilchards was proved (Walford and Mosher, 1943). Thus fish identified with certainty as belonging to year class 1938 have been marked by Nature with a characteristic that may continue to serve for distinguishing them as a group for several additional years.

Since the relation of scale length to body length can vary among year classes, it is necessary, for approximating past growth as accurately as possible, to determine a for each year class separately. To do this requires measurements over a sufficient range of sizes - therefore years of growth - to provide a significant measure of the regression. With present material, this was possible only for the four year classes mentioned above. Consequently in the following discussion, averages concerning those year classes alone have been adjusted as of formula (3) (page 13); and with the appropriate a values (page 13). For the rest, formula (1) has had to suffice.

Summarizing: To detect important anomalies in the past growth of the several year classes, the lengths at the past ages (f_n) were calculated by Lea's formula (1). These were averaged, and averages for year classes 1936 to 1939 were adjusted to take into account departures from exact proportionality of scale length to body length; in other words for the failure of the regression of scale length on body length to intersect with coordinates 0,0.[1] Values of $\bar{t}_n$ were obtained by subtracting $\bar{T}_n$ from $\bar{T}_n$-1.

The results of these calculations for the first year's growth increment ($\bar{t}_n$), given in Table 4, are remarkably variable. Among year classes 1932 to 1938 collected in 1939-40, for example, the average first year's growth increment ($\bar{t}_1$) ranged from 98 to 115 mm. Such apparent inconsistency could be caused by changes with age and size in the scale length-body length relationship. It could also occur if increasingly larger portions of the size range of each year class became available to the fishery as the year class became older. Or it might result from systematic errors in marking the location of the annuli, which were somehow associated with age.

[1] These adjustments were made graphically as follows: The average total length of a year class under consideration was located on the scale length-body length regression line, and a line drawn from there to the origin of the graph. Each $\bar{T}$ value for that year class was then located on the latter line; and the intersection between the ordinate passing through that point, and the scale length-body length regression line gave the adjusted value of that $\bar{T}$.

Table 4. - Average calculated first growth increments, by year classes

Year class	Average calculated length for fish collected in season of -					
	1939-40		1940-41		1941-42	
	Unadj. 1/	Adj. 2/	Unadj. 1/	Adj. 2/	Unadj. 1/	Adj. 2/
1932	111.83		108.97		110.00	
1933	114.02		115.20		111.26	
1934	102.22		107.04		106.48	
1935	104.49		107.62		103.84	
1936	97.95	99.4	101.98	103.0	102.74	104.3
1937	113.91	114.4	113.76	114.1	112.03	113.6
1938	115.14	123.6	108.93	118.5	99.89	113.0
1939			102.66	102.0	92.91	92.0
1940					116.73	

1/ Unadjusted figures.

2/ Adjusted for deviations from exact proportionality of scale length to body length.

It is reasonable to expect that all these causes would be progressive and rather regular in their effect, resulting in constant increase or decrease in comparable values of $\bar{t}$ with increase of age. Also, this trend should be continued in the collections of later years.

It is apparent at once from table 4, however, that far from progressing regularly, the comparable values of $\bar{t}$ fluctuated with no evident order in each of the three years of data studied. Thus it seems improbable that the fluctuations could be associated with age. On the other hand, it does appear that they are associated with year classes. If so, any given growth increment ($\bar{t}_n$) of a given year class should deviate from a norm of that increment in the same direction every year, as long as that class is wholly and significantly represented in the samples with respect to the increment in question. The meaning of this will become clear presently.

To establish a norm for $\bar{t}_1$, the $\bar{t}_1$ values for year classes 1932 to 1938, inclusive, were averaged, using the material collected during the season of 1939-40, and these grand averages were taken as norms for that season. Deviations of the $\bar{t}_1$ values for individual year classes were then plotted as curve number one in figure 6. The same procedure was followed with the material collected in the next season (1940-41), furnishing a second curve in figure 6. Although an additional year class, that of 1939, was present, it did not enter into that season's norm; but the deviation of its $\bar{t}_1$ value from the norm is indicated by a dotted line. Next the material collected in 1941-42 was similarly treated and the results plotted in the third curve of figure 6. Year class 1939 was not included in the norm, but deviations of its $\bar{t}_1$ value is indicated in figure 6 by dotted lines.

These three curves are closely similar. In all three, the first year's growth increment for year classes 1933, 1937, and 1938 deviates above the norm. In six out of seven points all three curves are in agreement. The probability that such agreement could occur by chance is slight.1/ In the absence of random occurrence, then, the agreement must mean that specimens having certain growth characteristics in common were allocated consistently to the same year classes three years in succession. It remains to be shown whether the allocation was correct.

EFFECT OF ENVIRONMENT ON THE GROWTH OF THE PILCHARD, AND ITS BEARING ON AGE DETERMINATION

If the anomalies described in the preceding section are a characteristic of the year classes, they must reflect some varying environmental condition that influences growth of body and scales. The most obvious such element is temperature. Surface temperatures of the sea at several points along the coast have been compiled by the Scripps Institution of Oceanography, and have kindly been made available for this study by the Director, Dr. H. U. Sverdrup. 2/

Mean temperatures, at these points, for calendar years and for various combinations of months for years 1932 to 1938 inclusive, were averaged, and deviations computed in the same way as had been done with the growth increments. In all combinations of months tried, the deviations from the norm are negatively correlated with the anomalies in the calculated first year's growth. The means of temperatures measured at Scripps Institution Pier for the period June to August, however, had a higher negative correlation than those for other localities and other combinations of months; and deviations from their norm are shown inverted as the fifth curve of the series in figure 6. The months represented are those in which growth of young pilchards is most rapid (cf. Walford and Mosher, 1943).

Of more fundamental influence than the temperature on the marine environment, hence on biology of the pilchard, is wind. For it is the northwest winds prevailing along the California coast during spring and summer that produce the phenomenon of upwelling. This results in the transport of nutrients to the surface waters, making them available to the plankton organisms. Thus, ultimately, it results in the production of food which the pilchard eats.3/

1/ The deviations given in the data collected in 1939-40 (top curve of fig. 6) are correlated with those corresponding in the data collected in 1940-41 (second curve of fig. 6), with an r of .93; and P of less than .01, according to Fisher's t test.

2/ Temperature data were studied for the following localities: Scripps Institution Pier at La Jolla, Lat. 32° 52' N.; the Pier at Balboa, Lat. 33° 36' N.; Huenome, Lat. 34° 9' N.; Pacific Grove, Lat. 36° 38' N.; North Farallon Island, Lat. 37° 42' N.; Blunt's Reef, Lat. 40° 27' N.

3/ For a discussion of the relation between wind and the circulation along the Pacific coast, see Sverdrup, 1938.2, 1938.3; Sverdrup and Allen, 1939.

Lacking available records of offshore wind force, a series was derived from barometric pressure data given on daily weather maps published by the United States Weather Bureau (cf. Sverdrup, 1938.2). First were tabulated the daily barometric pressures at each of the four corners of a 300-mile square, placed off the coast of southern California (cf. table 6). From these data were obtained two series of differences representing pressure gradients which would be expected to produce winds parallel and at right angles to the coast line, respectively; and their differences were summed by periods of time as described below.

The resulting two series of sums were treated, with due regard to the effect of the earth's rotation, as if they were components, the resultant of which is proportional to direction and extent of wind movement. The direction proved to be northwesterly for each period of the entire series studied.

Sums were made, as indicated above, for calendar years, and averaged for the period 1932-38, inclusive, to furnish a norm from which deviations were determined, as had been done with growth and temperature data, discussed above. The same procedure was followed using various periods of time and various combinations of months. Without exception the yearly deviations from normal indicated wind force were found to be correlated positively with anomalies in the first year's growth of pilchard. However, the period April through the following March gave a somewhat better correlation than other periods, and has been shown in the fourth curve of figure 6. This period corresponds with the first year's growth as registered on the scales: i.e., between the time of spawning and the time the first annulus is formed.

Other data bearing on the environment of the pilchard, made available by the Scripps Institution of Oceanography, are average monthly surface salinities for the same localities as cited in footnote 2, page 16. Those taken at the Scripps Institution pier were treated in the same way as described for the average monthly temperature records (page 16). Deviations from a norm based on the twelve-month period April to the following March - the same as that used for wind force - were plotted as the sixth curve of figure 6. This curve bears a strong similarity to the other five.

Thus is indicated a positive correlation between the force of northwest winds, the salinity of the surface water, and the first year's growth of pilchards; and a negative correlation between the latter and surface temperatures. To have demonstrated this required that the year classes, as determined from scales, be allocated correctly to the years in which they had been produced. It required also that a high enough order of accuracy be maintained in the scale reading to preserve the distinctive character of the curves.

A further conclusion to be drawn from these curves is that the fish of a given year class normally have a common history during their first year. They are subject to the same vicissitudes of marine climate and therefore probably also of food supply.

According to Lewis (1929), pilchards feed on diatoms and dinoflagellates, as well as upon copepods and other zooplankton. Moreover, the amount of food ingested is positively correlated with the abundance of surface plankton in the surrounding water. This in turn is controlled by temperatures; "low temperatures associated with upwelling of subsurface waters favor the growth of diatoms, which in turn attract the sardine" (lewis, op. cit., p. 179). This being true, it is reasonable to expect growth in abundance of diatoms to favor growth of pilchards.

For study of this question, Dr. W. E. Allen has kindly made available statistics on relative diatom abundance, which he has observed for several years at the end of the Scripps Institution pier at La Jolla and at Heuneme.[1/] Numbers of all species of diatoms per liter per week were summed by months; and the monthly totals summed in various groupings of months. No significant correlation between anomalies in these totals and anomalies in growth was found, no matter what grouping of months was used. However, the number of weeks in the year that the count of diatoms per liter exceeded 1,000, or 2,000 or 5,000, gave measures of diatom persistence, all of which showed a positive correlation with growth. As with the temperature and salinity data, these measures were summed by various combinations of months. The most satisfactory correlation was given by the number of weeks between June and the following May, inclusive, that the count exceeded 2,000 per liter. Deviations from the norm of that statistic taken over the period 1932-1938 are given in the seventh curve of figure 6. The period used, June through the following May, lags two months behind that used for wind data, and may indicate the time required for the action set up by the northwest winds to affect the supply of diatoms.

Although the abundance of diatoms thus appears to affect growth directly, it is a sustained abundance of these plants above a certain minimal level that is most effective in promoting growth, rather than sporadic flowerings of great abundance interspersed with periods of scarcity.

The relations between growth and other factors shown in figure 6 might not necessarily mean that pilchards normally spend the growing part of their first year of life near the locality where these data were collected. However, second and later growth increments were found not to be correlated with wind force, surface salinities, and temperatures measured at La Jolla. This may be explained in part by the fact that pilchards migrate successively greater distances as they grow larger, the extent of their migrations probably being a function of size more than of age. Consequently, the history of members of the same year class becomes less uniform as the fish grow older, though they probably never leave the Pacific coast save for seaward migrations of not more than 300 miles. This is all consistent with the conclusion that the bulk of pilchards in a year class do normally spend the first year of life in or near southern California, and that the subsequent history of the fish becomes so diverse that year-round conditions in any one locality can no longer reflect growth among the whole population of that year class.

[1/] For the method of sampling, see Allen, 1936.

The most striking inconsistency in figure 6 is the lack of correlation for 1939 between growth on the one hand and diatom persistence and surface salinity on the other; also between surface temperature and surface salinity. Although the surface water at La Jolla was abnormally warm in 1939, it was also of abnormally high salinity; and though the diatom count was high, the average growth of fish of the year was below normal.

The breakdown of correlation between temperature and salinity suggests an important anomaly in the current pattern in 1939 in the vicinity of La Jolla. The relatively weak northwest winds prevalent that year are consistent with relatively weak upwelling; and the increase in salinity and temperature can indicate an increase in the admixture of "southern water" (cf. Sverdrup, 1938). The biological evidence of a change in hydrographic conditions is equally suggestive. Certain species of diatoms normally occurring several weeks of the year at La Jolla were absent in Dr. Allen's samples of 1939, notably, Chaetoceros curvisetus, Chaetoseros laciniosus, Licmophora lyngbyei, and Lithodesmium undulatum. Among species occurring more frequently in 1939 than normally, those most noteworthy were Rhizosolenia alata, Rhizosolenia fragilissima and Rhizosolenia imbricata. The ecology of these species is too little known to permit of interpreting their occurrence in terms of physical oceanography. It may be of significance, however, that among species of the first group mentioned above, all have been listed by Cupp and Allen (1938) as being south temperate neritic forms, except Licmophora lyngbyei, which is "tychopelagic". Among those listed in the second group, Rhizosolenia alata is an oceanic temperate form; and the other two are north temperate forms.

More direct evidence that a change in the environment of the pilchards took place in 1939 is the fact that an abnormally high production of young pilchards occurred that year in waters far to the north of southern California, which is regarded as the usual chief spawning ground. This may have been the result of abnormally high survival of young hatching from the number of eggs normally spawned north of California. It may also have been the result of abnormally heavy egg production in northern waters, permitted by a northward extension of oceanographic conditions favoring spawning. In support of the latter hypothesis is the fact that adult pilchards taken by fishermen in mid-summer off Oregon and Washington were full of spawn, in contrast to their usual immature condition at that time. That spawning actually occurred north of California is proved by the fact that the Fish and Wildlife Service that year collected pilchard eggs and larvae in tow nets off the Oregon coast (Walford and Mosher, 1941).

Whatever may account for it, an extraordinary number of young pilchards of year class 1939 were subsequently observed and caught from Oregon to Alaska, as well as along the California coast. It has been previously observed that the first year's growth decreases northward (Walford and Mosher 1943). Thus the northward extension of the range of year class 1939 could alone account for its abnormally low first year's growth in spite of the apparently favorable food supply in southern California.

SUMMARY AND CONCLUSIONS

Annual rings appear on the scales of adult pilchards, as in the young, and at the same time of year, namely, the winter and early spring. If the scales be properly prepared, these rings can be recognized and distinguished from false age marks by means of criteria set up in this study. The accuracy of following these criteria differs among readers and for different ages of fish being lower for older ages than for younger ones, but for the age distribution prevailing from 1939 to 1942, and for the persons reading the scales in this study, it averaged near to 93 percent.

The most important evidence supporting the validity of age determination by scales is that the fish allocated to each year class had growth characteristics in common, which appeared consistently in three seasons of sampling. These characteristics were expressed as the average first year's growth increment, calculated from scales. Departures of these averages from a norm were significantly correlated with anomalies in certain elements of the environment, thereby proving that the identification of the year classes had been correct.

The correlations indicated that, in general, growth during the first year is favored by a sustained presence of diatoms at optimum abundance. In turn, the latter is favored by upwelling, which is induced by northwest winds, and accompanied by low surface temperatures and high surface salinity, at least at the locality of observation.

In addition to an abnormally high first year of growth, year class 1938 was marked by having scales which averaged smaller than normal in relation to the length of the body.

No mtthod has yet been devised of measuring the error of scale reading occasioned by the scales being irregularly marked; i.e., having too many or too few age rings. If this error were unduly high, however, specimens assigned to a given year-class would actually be composed of several ages; and if such mixing be complete, the average growth of the several year-classes should be uniform. In that event, the correlations referred to above would have become obliterated. The demonstration of the correlations, and their persistence for three seasons is evidence that the error was reasonably low, we judge, for the age composition prevailing, something of the order of ten percent or less. Thus, the relatively high accuracy of age determination of pilchards by scale reading--between 80 and 90 percent--and the fact that results are reproducable by different persons, warrants the confident utilization of this technique in the program of pilchard research.

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Figure 1. Left - A scale with 4 rings, the fourth close to the edge and touching it at the base of the sculptured portion.

Right - A scale with 4 rings, the fourth well within the edge.

Owing to their large size, irregular surface, and fine structure of the external folds, sardine scales do not photograph well.

In reading scales, it is necessary to focus continually, and sometimes to alter the lighting in order to see all parts of all rings. The following plates show one what can be seen at a particular focus and lighting.

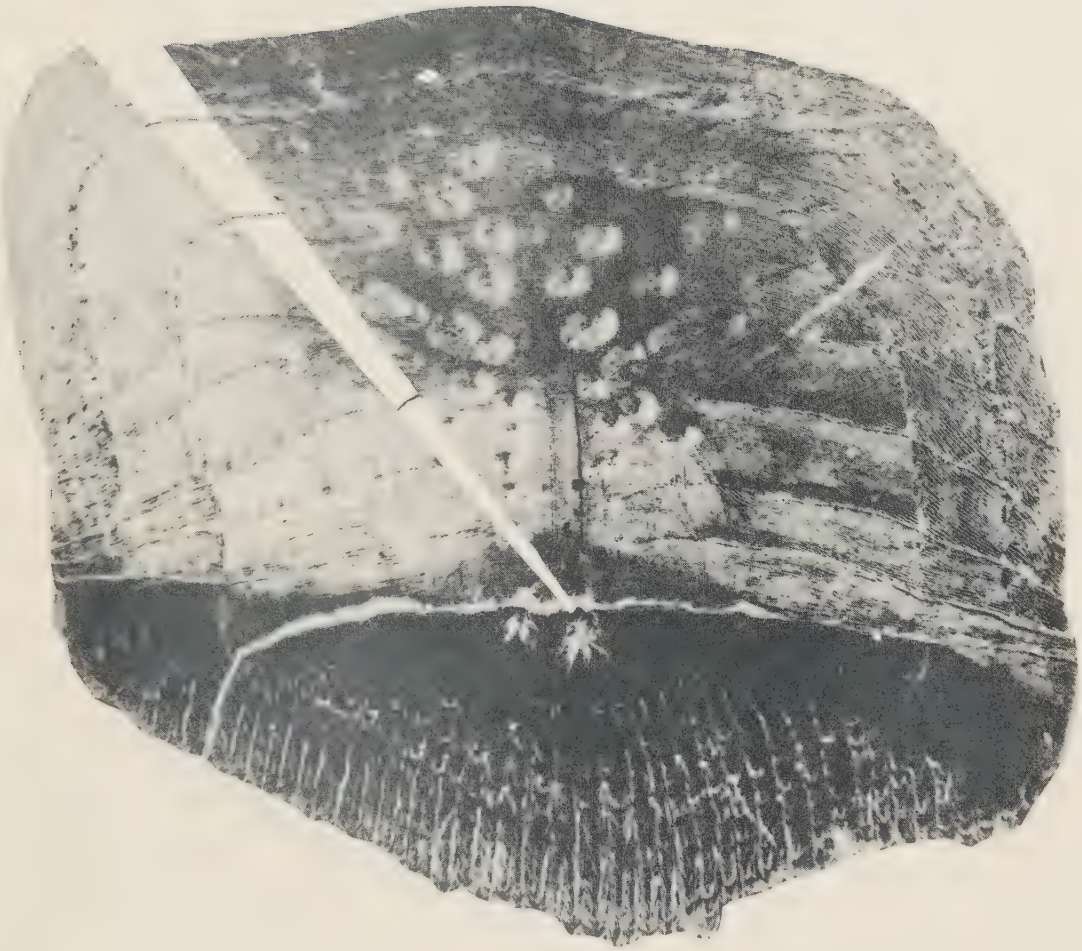

Figure 2. A pilchard scale with three rings, with a wide margin beyond the third ring.

Figure 3. A pilchard scale with 5 rings.

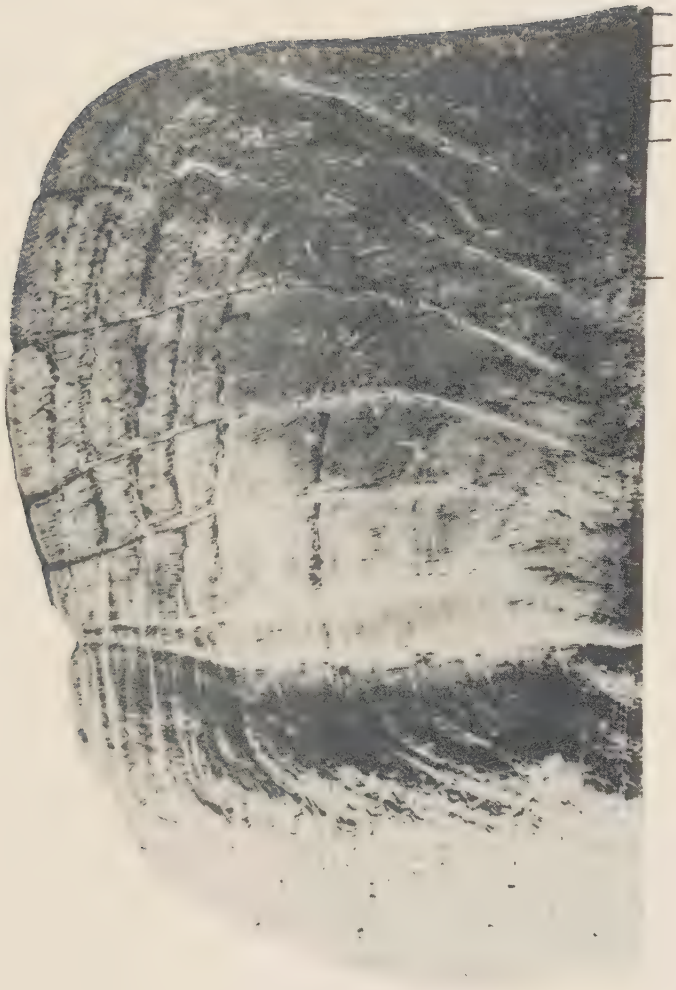

Figure 4. A pilchard scale with six rings.

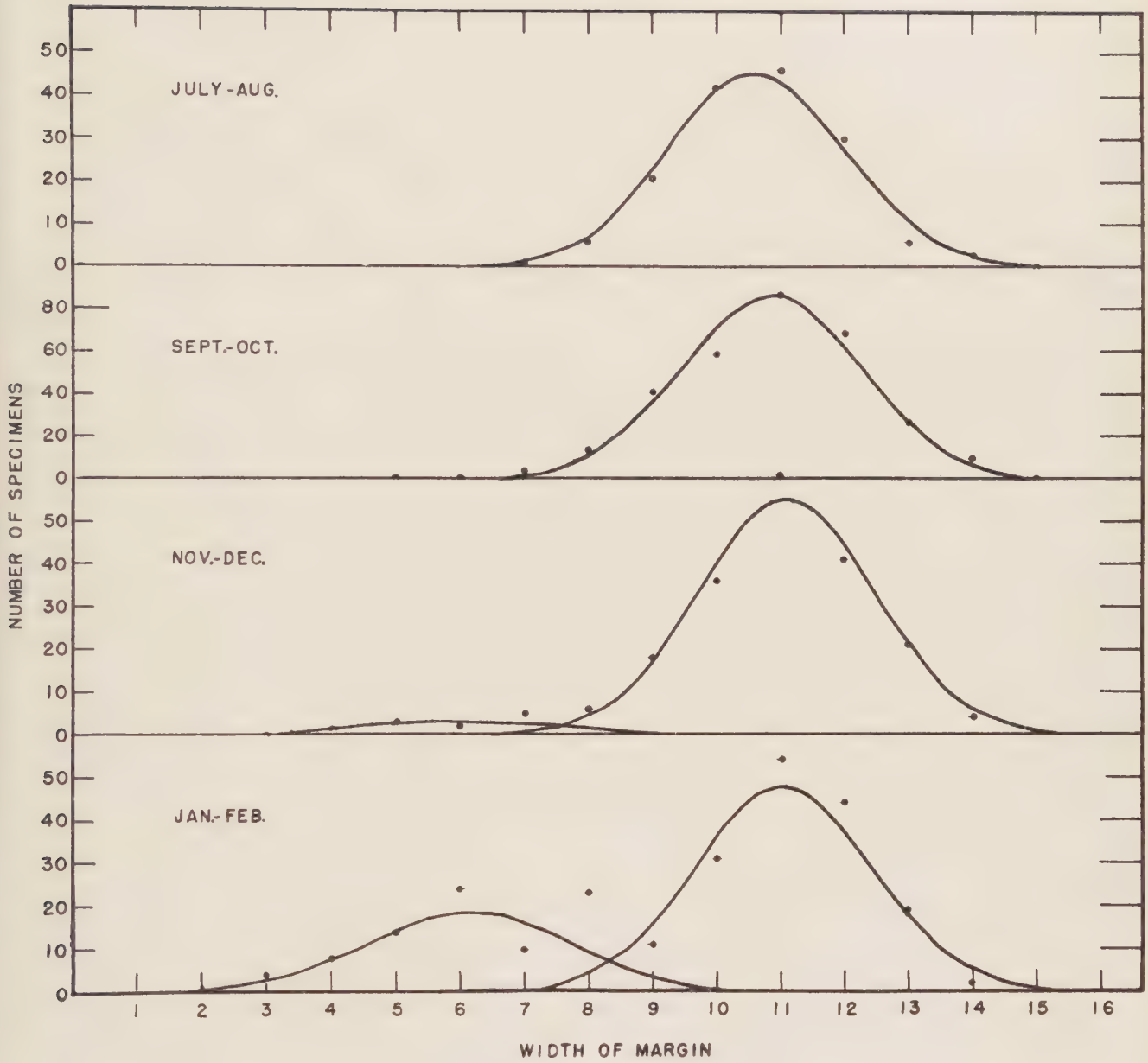

Figure 5. - Frequencies of widths of margin beyond last ring in scales having four rings. The data are fitted with normal curves to distinguish specimens having a recently formed annulus.

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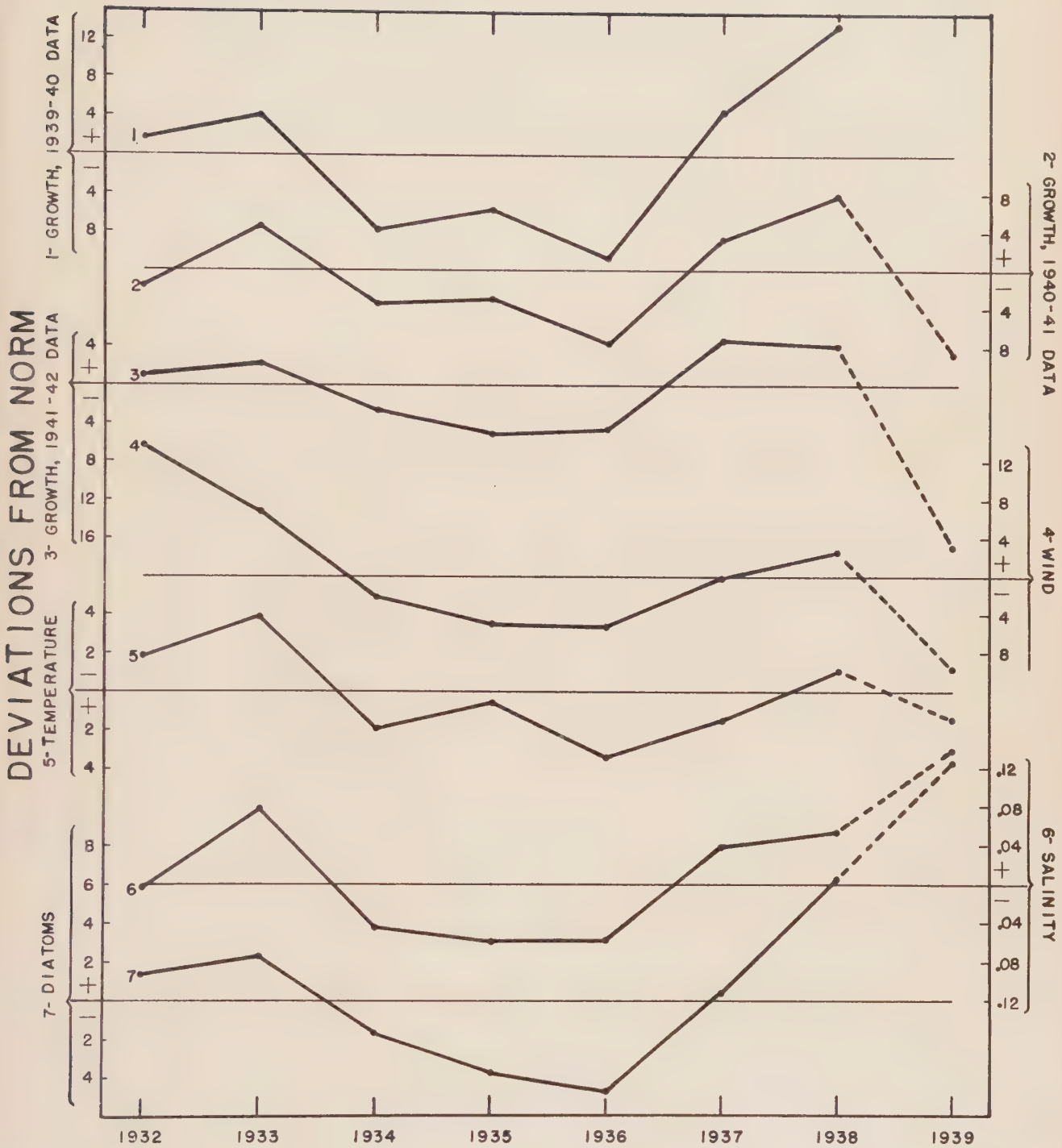

Figure 6. - Deviations from seven-year norm of growth in body length as computed from scales collected during three seasons, compared with similar deviations for various elements of the environment.

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Table 5.- Frequencies of body lengths of pilchards at end of first year as calculated from scales

Body length	YEAR-CLASS 1932			1933			1934			1935			1936		
	Collected in season of			Collected in season of			Collected in season of			Collected in season of			Collected in season of		
	'39-'40	'40-'41	'41-'42	'39-'40	'40-'41	'41-'42	'39-'40	'40-'41	'41-'42	'39-'40	'40-'41	'42-	'39-'40	'40-'41	'41-
51- 54	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
55- 58	-	-	-	-	-	-	-	-	-	1	-	-	-	1	1
59- 62	-	-	-	-	-	-	-	-	-	-	-	-	6	2	-
63- 66	-	-	-	-	-	-	1	-	-	-	1	-	5	5	3
67- 70	-	-	-	-	-	-	2	1	-	2	-	-	20	7	-
71- 74	1	1	-	2	-	-	3	1	1	3	1	-	32	15	7
75- 78	1	-	-	-	2	-	4	2	-	7	2	1	52	19	14
79- 82	5	1	-	3	2	2	19	2	1	8	3	3	70	40	16
83- 86	6	1	-	7	1	-	17	4	5	16	9	5	89	51	19
87- 90	4	-	-	6	1	1	19	10	4	18	13	6	90	84	33
91- 94	10	2	1	5	-	1	24	18	2	24	20	5	67	67	31
95- 98	10	13	-	10	4	2	27	20	7	29	27	16	76	90	39
99-102	16	7	1	19	4	4	20	27	4	22	36	12	64	87	40
103-106	9	7	-	17	6	1	21	24	1	40	34	9	84	84	34
107-110	11	4	1	24	14	1	27	25	9	30	49	16	66	90	37
111-114	11	5	-	20	7	2	10	14	7	26	28	10	62	76	22
115-118	15	5	1	18	10	3	14	23	3	11	27	4	47	53	26
119-122	11	2	-	17	10	6	9	9	1	19	20	8	40	51	15
123-126	7	4	-	13	11	1	12	6	1	11	24	-	24	42	10
127-130	6	3	1	12	8	1	6	10	1	10	11	2	29	18	11
131-134	9	-	-	9	7	-	7	7	-	5	8	2	9	11	7
135-138	3	-	-	11	2	1	1	3	1	4	2	-	12	6	6
139-142	3	2	-	6	3	-	2	2	3	2	3	-	3	3	4
143-146	8	2	-	6	-	-	4	-	1	4	1	-	2	2	1
147-150	3	-	-	1	-	-	2	-	-	1	-	-	1	-	1
151-154	1	1	-	4	-	1	-	-	1	1	-	-	-	1	-
155-158	-	-	-	-	-	-	-	1	-	-	-	-	-	-	-
159-162	-	-	-	-	-	-	-	-	-	-	1	-	-	-	-
Totals	150	60	5	210	92	27	251	209	53	294	320	99	950	906	377

1/ Figures are not adjusted to take into account departures from exact proportionality of scale length to body length.

Table 5 (Cont'd.)Frequencies of body lengths of pilchards at end of first year as calculated from scales

Body length	YEAR-CLASS 1937 Collected in season of '39-'40	1937 Collected in season of '40-'41	1937 Collected in season of '41-'42	1938 Collected in season of '39-'40	1938 Collected in season of '40-'41	1938 Collected in season of '41-'42	1939 Collected in season of '40-'41	1939 Collected in season of '41-'42	1940 Collected in season of '41-'42
51- 54	-	-	-	-	-	-	-	-	-
55- 58	-	-	1	-	-	2	-	1	-
59- 62	-	1	1	-	-	-	1	3	-
63- 66	1	2	1	-	1	12	-	29	-
67- 70	-	3	3	-	1	17	2	69	1
71- 74	1	2	3	-	6	49	6	147	-
75- 78	5	11	12	-	4	64	7	242	-
79- 82	8	7	11	-	14	131	6	365	2
83- 86	14	19	26	2	27	184	14	442	2
87- 90	23	37	32	9	37	238	29	542	5
91- 94	38	32	35	12	59	261	24	559	6
95- 98	53	55	57	34	68	237	30	490	11
99-102	87	82	54	35	78	231	41	405	17
103-106	106	144	78	54	92	226	34	304	32
107-110	146	145	73	66	94	170	30	216	38
111-114	129	147	69	93	78	162	33	119	68
115-118	147	177	86	74	73	128	25	75	66
119-122	122	157	69	86	73	81	24	30	59
123-126	102	119	68	62	71	76	15	28	40
127-130	91	93	40	59	38	42	1	8	37
131-134	76	58	36	26	32	31	1	10	25
135-138	36	39	29	13	18	15	2	4	9
139-142	11	27	23	9	8	5	-	3	6
143-146	5	14	12	3	4	1	-	2	3
147-150	4	4	3	-	-	2	-	-	1
151-154	-	1	-	-	-	1	-	-	-
155-158	-	-	1	-	-	-	-	-	-
159-162	-	-	1	-	-	1	-	-	-
Totals	1205	1376	822	637	876	2367	325	4093	428

Table 5 (Cont'd.) Frequencies of body lengths of pilchards at end of first year and calculated from scales

Totals by Districts	YEAR-CLASS 1932 Collected in season of '39-'40	'40-'41	'41-'42	1933 Collected in season of '39-'40	'40-'41	'41-'42	1934 Collected in season of '39-'40	'40-'41	'41-'42	1935 Collected in season of '39-'40	'40-'41	'41-'42	1936 Collected in season of '39-'40	'40-'41	'41-'42
California															
S. P.	-	-	-	-	-	-	-	-	1	-	-	6	-	-	28
Mont.	12	-	-	38	-	-	44	-	1	184	-	3	917	-	33
S. F.	-	17	-	-	24	-	-	35	2	-	114	2	-	546	28
Oregon	-	6	-	-	13	2	-	17	3	-	18	2	-	56	20
Washington	138	12	2	172	14	13	207	48	20	110	87	29	33	134	74
Brit. Col.	-	25	3	-	41	12	-	109	26	-	101	57	-	170	194

Totals by Districts	YEAR-CLASS 1937 Collected in season of '39-'40	'40-'41	'41-'42	1938 Collected in season of '39-'40	'40-'41	'41-'42	1939 Collected in season of '40-'41	'41-'42	1940 Collected in season of '41-'42
California									
S. P.	-	-	99	-	-	763	-	1152	178
Mont.	1205	-	134	637	-	737	-	1632	211
S. F.	-	1288	144	-	876	590	325	695	9
Oregon	-	20	31	-	-	51	-	161	6
Washington	-	43	145	-	-	101	-	264	19
Brit. Col.	-	25	269	-	-	125	-	189	5

1/ San Pedro

2/ Monterey

3/ San Francisco

Table 6. - The symbols "a", "b", "c", "d" refer to the four corners of the square, mentioned on page 29, for which barometric pressures (in inches of mercury) A, B, C, D, respectively, were calculated by interpolation between isobars on daily weather maps. The figures given are monthly sums of these daily interpolations. The points are located approximately as follows:

a, lat. 32° 26' N.; long. 126° 12' W.; b, lat. 35° 16' N., long. 121° 15' W.; c, lat. 30° 58' N.; long. 118° 28' W.; d, lat. 28° 16' N.; long. 123° 17' W.

They are so placed that (A+D) - (B+C) will give a pressure gradient in a direction from which one would infer a wind parallel to the coast line, assuming deflection to be 73 degrees. Similarly, the difference between (A+B) and (C+D) would give a pressure gradient from which a wind at right angles to the coast would be inferred. For the study discussed in this paper, the aforesaid differences were computed from twelve-month summations of the monthly sums of daily pressures. They were treated as components, and converted to their corresponding resultants (R) with the following formula:

$$R = \sqrt{[(A+D) - (B+C)]^2 + [(A+B) - (C+D)]^2}$$

Table 6 (Cont'd.)

	1932 A	1932 B	1932 C	1932 D	1933 A	1933 B	1933 C	1933 D	1934 A	1934 B	1934 C	1934 D
Jan.	937.503	934.254	933.481	935.456	936.599	931.748	930.689	931.831	937.989	935.982	933.025	934.720
Feb.	872.162	870.575	870.115	871.226	847.543	845.450	842.827	844.598	841.877	842.868	842.739	842.727
Mar.	935.457	932.554	930.931	932.860	934.889	932.997	931.767	934.214	934.818	932.747	931.110	933.473
Apr.	903.458	900.785	899.648	902.056	904.809	900.820	899.772	902.958	902.926	900.254	898.987	901.690
May	933.356	929.833	929.274	931.993	935.294	931.828	930.781	934.099	933.985	929.577	928.531	931.759
June	901.243	897.184	896.647	899.491	902.986	899.557	899.134	901.782	902.355	898.807	898.438	901.479
July	932.459	927.924	927.714	930.151	932.418	927.435	926.944	930.344	932.737	929.228	928.750	931.359
Aug.	930.615	926.625	926.515	929.183	931.178	927.601	926.658	929.485	932.116	929.201	928.427	930.414
Sept.	902.014	897.695	897.453	899.736	901.148	896.811	896.610	899.534	901.107	896.614	896.408	899.179
Oct.	932.610	929.759	928.143	930.032	932.061	929.572	928.537	930.611	931.310	930.672	929.244	930.772
Nov.	903.554	902.464	900.409	901.978	905.609	903.612	900.927	903.324	903.722	902.914	900.980	903.052
Dec.	934.674	933.557	931.511	932.749	933.464	933.721	932.901	933.401	935.011	933.956	931.083	932.310

	1935 A	1935 B	1935 C	1935 D	1936 A	1936 B	1936 C	1936 D	1937 A	1937 B	1937 C	1937 D
Jan.	931.398	932.337	930.863	931.153	932.973	932.717	930.934	931.927	934.359	932.691	931.962	933.671
Feb.	844.492	843.874	841.610	842.687	871.477	870.642	870.490	870.988	842.571	842.133	841.963	843.208
Mar.	934.203	931.849	931.368	933.275	932.155	929.979	929.129	930.383	931.145	929.812	929.318	930.714
Apr.	900.938	899.524	899.365	901.583	903.470	902.235	901.782	902.768	905.072	902.505	900.420	903.218
May	932.979	928.799	928.299	931.281	932.030	929.008	927.071	931.145	932.734	928.343	927.707	931.072
June	902.639	897.956	897.884	901.382	900.523	897.752	897.061	899.881	901.376	898.911	898.248	900.630
July	932.253	928.568	927.965	929.878	931.013	926.946	926.699	929.158	932.191	928.394	926.672	930.515
Aug.	929.238	926.548	925.131	926.838	931.428	927.665	927.031	929.545	931.809	928.538	927.672	929.804
Sept.	900.191	898.135	896.985	898.931	899.533	896.319	895.910	898.179	901.258	898.041	896.903	899.360
Oct.	932.282	930.607	928.907	930.704	931.466	929.075	928.161	930.087	931.453	929.601	928.297	930.648
Nov.	904.224	902.459	901.311	902.378	903.985	903.471	900.497	900.915	904.567	902.162	901.390	903.146
Dec.	932.625	932.188	930.741	931.882	933.114	931.756	930.535	931.322	932.535	932.482	930.623	931.305

	1938 A	1938 B	1938 C	1938 D	1938 A	1938 B	1938 C	1938 D	1940 A	1940 B	1940 C	1940 D
Jan.	935.436	934.033	931.389	933.660	935.803	932.795	931.016	934.159	931.006	931.936	932.132	932.694
Feb.	840.539	840.935	841.403	841.709	847.656	844.378	842.861	845.337	872.077	872.173	872.340	872.401
Mar.	931.252	931.167	930.817	932.559	935.508	932.832	932.446	934.484	933.038	931.453	930.551	932.067
Apr.	904.124	901.164	900.116	903.103	904.325	901.264	900.645	902.687				
May.	933.012	929.655	928.714	931.683	932.814	928.755	929.182	932.076				
June	901.903	898.261	897.768	899.231	902.166	898.535	897.907	900.280				
July	932.067	929.119	929.036	930.787	932.526	928.865	928.340	931.167				
Aug.	931.276	928.148	927.785	929.887	931.086	928.647	928.049	929.766				

Table 6 (Cont'd.)

	1938 A	B	C	D	1939 A	B	C	D
Sept.	899.150	897.725	897.209	898.932	899.929	897.328	896.329	898.018
Oct.	932.071	929.812	930.184	931.277	933.200	930.857	929.658	931.459
Nov.	904.716	903.350	901.035	902.435	904.560	902.551	900.911	903.103
Dec.	933.773	932.562	931.487	932.633	934.361	933.728	932.614	934.380

Table 7.-Average monthly surface temperatures in degrees centigrade at Scripps Institution Pier, La Jolla, California. Recorded by Scripps Institution of Oceanography.

YEAR	JAN.	FEB.	MAR.	APR.	MAY	JUNE	JULY	AUG.	SEPT.	OCT.	NOV.	DEC.
1932	13.28	13.27	14.80	14.81	16.08	18.99	19.49	18.75	18.62	17.40	16.18	14.00
1933	13.01	12.60	13.46	14.90	15.39	17.27	18.65	19.04	16.96	17.22	15.42	13.91
1934	13.27	13.95	15.74	17.32	19.21	19.06	20.47	20.47	20.55	17.87	16.96	15.46
1935	14.39	14.05	13.26	15.04	17.59	18.87	19.98	20.74	19.36	17.19	15.29	14.76
1936	13.97	14.64	15.11	14.24	18.08	17.96	22.35	22.08	20.95	18.57	17.28	16.10
1937	13.43	13.13	14.25	14.90	17.71	19.11	20.76	20.63	20.58	17.73	16.97	15.30
1938	15.01	14.39	14.59	15.12	16.71	17.84	19.07	20.98	20.06	17.05	14.52	14.78
1939	14.08	11.96	13.21	15.53	16.68	18.36	20.69	21.31	19.45	19.23	18.17	17.43
1940	15.84	15.19	15.05	16.47	18.60	18.16	18.34	20.63	19.22	18.62	16.03	16.11

Table 8.-Average monthly surface salinity[1/] at the Scripps Institution Pier, La Jolla, California. Recorded by Scripps Institution of Oceanography

YEAR	JAN.	FEB.	MAR.	APR.	MAY	JUNE	JULY	AUG.	SEPT.	OCT.	NOV.	DEC.
1932	.64	.21	.39	.62	.67	.69	.68	.59	.56	.49	.57	.53
1933	.49	.45	.54	.58	.69	.80	.77	.76	.66	.68	.68	.62
1934	.54	.53	.53	.61	.67	.68	.68	.58	.61	.52	.52	.43
1935	.40	.28	.42	.51	.60	.65	.62	.59	.51	.50	.49	.54
1936	.51	.26	.46	.58	.64	.67	.75	.72	.66	.45	.55	.52
1937	.40	.25	.04	.37	.57	.68	.72	.75	.76	.67	.71	.62
1938	.70	.66	.15	.66	.73	.78	.79	.75	.65	.56	.57	.53
1939	.43	.49	.57	.61	.75	.81	.86	.82	.62	.68	.72	.76
1940	.72	.60	.63	.58	.71	.70	.64	.71	.57	.52	.44	.37

1/ Figures given are minus 33.00; i.e., add 33.00 to obtain actual salinities.

Table 9.-Number of weeks[1], by months, that counts of diatom cells, as sampled by W. E. Allen[2], at the Scripps Pier, La Jolla, were of various categories of magnitude

YEAR	DIATOM COUNT	JAN.	FEB.	MAR.	APR.	MAY	JUNE	JULY	AUG.	SEPT.	OCT.	NOV.	DEC.
1932	499 or less	-	-	3	-	-	-	-	1	1	4	-	1
	500 -- 999	-	1	-	-	-	-	3	2	-	-	2	-
	1,000 -- 1,999	2	-	-	-	-	-	1	-	1	1	2	-
	2,000 & more	2	4	1	4	5	4	-	2	2	-	-	3
1933	499 or less	-	-	-	-	-	1	-	-	1	-	-	-
	500 -- 999	-	-	-	-	-	2	1	2	1	-	-	-
	1,000 -- 1,999	1	1	-	-	-	-	-	-	1	1	1	1
	2,000 & more	3	3	5	4	5	1	3	3	1	3	3	4
1934	499 or less	-	-	3	-	-	-	1	-	2	2	1	2
	500 -- 999	-	-	1	-	1	-	1	1	1	-	-	1
	1,000 -- 1,999	2	-	-	-	-	-	2	3	-	1	1	-
	2,000 & more	2	4	1	4	4	4	-	1	1	1	3	1
1935	499 or less	1	-	-	-	1	-	-	-	-	1	1	-
	500 -- 999	1	-	-	-	2	1	-	2	-	1	3	2
	1,000 -- 1,999	-	1	-	-	-	2	-	-	2	-	1	1
	2,000 & more	2	3	5	4	1	2	4	3	2	2	-	1
1936	499 or less	-	2	1	-	4	-	-	-	2	1	2	3
	500 -- 999	-	1	-	-	1	1	-	-	2	-	1	1
	1,000 -- 1,999	2	1	2	1	-	-	-	1	-	3	1	1
	2,000 & more	2	1	1	3	-	3	4	4	-	-	-	-
1937	499 or less	-	2	1	-	-	-	1	1	-	2	-	1
	500 -- 999		-	1	-	2	1	2	2	-	1	2	1
	1,000 -- 1,999	1	-	-	-	2	-	-	-	1	-	2	1
	2,000 & more	3	2	3	4	1	3	1	2	3	1	1	1
1938	499 or less	1	-	-	-	-	-	-	-	-	1	-	4
	500 -- 999	-	-	-	-	-	-	-	-	-	-	-	1
	1,000 -- 1,999	2	-	2	1	-	1	-	2	-	-	-	-
	2,000 & more	1	4	3	3	5	3	4	3	4	3	4	-
1939	499 or less	-	-	1	-	-	-	-	1	-	-	-	-
	500 -- 999	1	-	1	-	-	-	-	1	-	-	-	-
	1,000 -- 1,999	2	-	1	-	-	1	-	1	-	-	-	3
	2,000 & more	1	4	2	4	5	3	4	1	5	4	5	1
1940	499 or less	-	-	-	-	-	-	-	-	-	-	-	1
	500 -- 999	1	-	-	-	-	-	-	-	-	1	-	1
	1,000 -- 1,999	-	1	1	1	-	-	-	-	1	1	-	1
	2,000 & more	3	4	3	3	5	4	4	5	3	3	4	1

1/ A week divided between two months was assigned to whichever one of them included most of its days.

2/ Cf Allen, 1936, for method of sampling.